

WILE ORFACETS: SCIENCE, BEHAVIOR, AND ACQUISITION COMMUNICATION  
(ORFACETS: SCIENCE, BEHAVIOR, AND ACQUISITION COMMUNICATION)

By

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I greatly appreciate the efforts of many friends and professors in the Entomology and Civil Engineering Departments who helped me in many ways during the course of my field and laboratory work, and I am grateful to them.

## PROBLEM

Post graduate students encounter a problem like the one I faced during Fall 1970. What should I do for my dissertation? I discussed my problem with many professors, Dr. J. E. Lloyd was helpful with his counselling and his suggestions made me become a field entomologist. I made up my mind to work on the basic aspects of an economically important insect. While I was conversing with Dr. T. A. Walker during December 1970, he pointed out that little was known about mole crickets. I reviewed the literature on mole crickets for a paper at the Florida Entomological Society meeting in Fall 1971, and I became convinced that I should work on the basic biology of mole crickets. I was safely interested in answering questions that were important to the control of mole crickets. Dr. Walker taught me how to go about making the right kind of questions on important questions that can be tackled with scientific equipment. The work reported here has been presented in five annual meetings: Fla., Florida Entomological Association (Gainesville - 1970), Florida Entomological Society (Tampa - 1970, Miami - 1970), and Entomological Society of America (Dallas - 1971, Memphis - Southeastern Branch - 1970). A part of my mole cricket research has appeared in Science (1973, 1974, 1975).

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The southern silk crickets, Scaphiocratus scutellatus (Fabricius) and Scaphiocratus  
virgatus (L.), are pests of turf and agricultural areas  
in the southeastern United States. They may have undesirable life cycles.  
Both species fly during spring and fall in Gainesville, Florida. During  
1973, spring collections included 5000 adults (5000 virgatus) and fall  
collections had 100 adults (100 virgatus). During 1973 and 1974, females  
comprised 1/3 of those collected of both virgatus ( $n = 1141$ ) and scutellatus  
( $n = 1200$ ). Out of 1044 adults virgatus marked and released, 35 were  
recaptured, proving that at least 25 of adults fly more than once. Three  
adults were recaptured before. Recaptured were made up to 6 1/2 weeks and  
at distances as great as 8 1/2 km. Scaphiocratus flight speed was estimated  
at 2-11 mph in a calm night.

Phonotaxis (via, recorded or played to sound) of flying crickets was  
demonstrated for the first time, and may provide a new method of control  
for silk crickets. When calling songs of virgatus and scutellatus were broadcast  
through outdoor loudspeakers, large numbers of these two species  
flew in their respective calling songs. Adult females were more fre-  
quently captured than males were, and males were 1/3 of the catch.

crickets of these other subspecies were stopped as they flew to male cricket calling songs resembling their own. Experiments concerning effects of different parameters of synthetic male gryllus sounds on flying gryllus proved that gryllus distributed called frequency and pulse rate.

Males produced calling songs after sunset for 1 h to 1.5 hours in specially constructed subsurface chambers. The mean carrier frequency, pulse rate, and intensity of gryllus calling songs were 2.7 kHz, 55 pulses per second (pps) and 49 dB (at 15 cm), and of gryllus were 3.3 kHz, 70 pps, and 45 dB respectively. Males of gryllus and gryllus produced aggressive and courtship songs similar to calling songs with respect to carrier frequency and pulse rate. Sexual protection by females of gryllus spp. has never been reported, but female gryllus made sounds with energy at frequencies varying from 2 to 4 kHz. Courtship behavior of gryllus included long and short intermittent trills of songs, and tapping of the tail with the forelegs.

Cannibalism was observed once each in captive gryllus and gryllus. In both species, 70% of flying adults (n = 110) had an empty crop. Others had plant materials and insect parts.

Although pulsed belts have been observed by counting dead male crickets on the surface, none do fly in their burrows.

## INTRODUCTION

Mole crickets are subterranean crickets belonging to the order Orthoptera and family Gryllacrididae. This family has 3 genera and 47 species (Shepard 1944). Mole crickets can be easily distinguished from other crickets by their short anterior legs, with enlarged foretibiae adapted for digging. They are nocturnal pests attacking lawns, pastures, and a variety of crops. Although research on the control of mole crickets has been carried on for the last 7 decades, mole cricket problems have continued. The lack of real progress may be due to the lack of basic information on mole cricket biology—especially behavior and ecology. Therefore, I concentrated on these aspects.

Shepard (1944) has recently surveyed the literature on mole crickets. Numerous authors have reported control measures for mole crickets, but only a few have reported their life histories. I will discuss pertinent literature in the appropriate chapters later.

I studied two species of mole crickets: the southern mole cricket, Scaphiocratus nigratus Rehn and Howard, and the change, S. viridis Scudder. They can be easily identified by morphological characters (Blatchley 1928). In this dissertation, I describe their seasonal life cycles, sound production, associated behavior with special reference to phonotaxis, dispersal, food habits, and other aspects of their biology.



CHAPTER I  
GEOGRAPHICAL AND ECOLOGICAL DISTRIBUTION OF WOLF CRICKETS

Wolf crickets occur across the world approximately between latitudes 35° N and 35° S. The genus Scaphocephalus occurs in the New World, India, and Madagascar (Chopard 1944). S. aspinus and viridis are found in the southern United States (Fig. 1-1). S. aspinus is a native species and viridis is probably introduced. S. viridis is known to occur in Cuba, Puerto Rico, Trinidad, and humid sandy areas of the northern part of South America. It appears that viridis was introduced into the United States from the West Indies (Houston and Reed 1911) since 1895. Garrett (1960) reported the common half-bird of Puerto Rican agriculture that viridis arrived in Puerto Rico from South America circa 1850. He believed that viridis was present earlier than 1850 in Puerto Rico. McIntosh (1941) failed to find a natural enemy for viridis in Puerto Rico but found a new, Larus argentatus (seagulls), in Cuba, Brazil, and introduced it to Puerto Rico. It appears that viridis is native to northern South America.

Wolf crickets are nocturnal and can be found in wet to moist sandy areas where natural vegetation has been considerably disturbed. They are not known from wooded areas. The common habitats of aspinus and viridis are lawns, golf courses, borders of highways, pastures and annually plowed fields (corn), gardens, nurseries, and crop lands). S. aspinus, but not viridis, occurs near the edges of lakes, ponds, and streams.

## CHAPTER 2 SEASONAL LIFE CYCLES OF SOLE CRICKETS

Three kinds of life cycles have been reported in sole crickets: annual, continuous breeding, and semivoltinism (one generation each year), and semivoltinism (one generation each two years). A few workers have carefully studied the life cycles of sole crickets. In tropical Puerto Rico, sole crickets may breed all the year. While studying the life history of gigantes in Aguadon, Puerto Rico, Van Duzendburg (1938) found that females laid eggs in an extraordinary early month of the year (month December) and that all the stages were found in the field at any time of the year. Kapoff (1940) studied the life cycles of gigantes and viridis in Plant City, Florida, by rearing the sole cricket adults in shaded pens covered with various lids. He concluded that gigantes and viridis were univoltinism and that eggs were laid from April to July. He reported that 75% of gigantes and 75% of viridis overwintered as nymphs. The remainder overwintered as adults. He did not mention the time or length of overwintering nymphs. Tanaka and Tanakigawa (1953) studied the seasonal life cycle of Scyllisthylum affricum Bellard de Beauv. in Japanese sugarcane fields. They reported that eggs were laid from April to July and adults emerged after 10 months. Several workers have studied the life histories of European sole crickets and all reported life cycles longer than one year. Morales (1940) found in Spain that S. scyllisthylum Clavensis had one generation each two years. A similar semivoltinism life cycle was recorded from East Germany by Bahr (1958), who showed that the nymphs developed into adults after 100 days.

Rearing substrata used in rearing of male arctids affect the developmental period of eggs. In Germany, Stefan (1966) divided the eggs of *B. pallasiensis* from the same batch of eggs into two groups: eggs fed on honey feed completed life cycles in 3 years while eggs fed on vegetable matter had a longer developmental period—over four years.<sup>1</sup>

### Methods

Laboratory studies of *salinus* and *glaucus* were conducted in plastic boxes (20 x 20 x 10 cm) partly filled with soil. Single females and male-female pairs were confined in the boxes and fed dry dog food (Purina dog chow<sup>®</sup>). The male arctids used were captured either in stream flights or at hibernating headquarters (for details see page 16). Unless otherwise specified, the male arctids were caught during spring and early summer 1971. In this time, I started rearing 26 pairs of each of *salinus* and *glaucus*, and 12 to 25 females of *salinus* and *glaucus*. I examined the rearing boxes at one week to six week intervals and made observations on the hatch of eggs, nymphs, and adults. Every of male arctid eggs was by flooding the rearing box with water and filtering the water-suspended soil through a wire screen filter. The eggs were reburied in moist soil by placing all the eggs in a soil 2 cm in diameter.

Field rearing was carried out at the Entomology Farm (Shang Fong). Single pairs of *salinus* and of *glaucus* were confined in clay pots (30 cm diameter x 25 cm height) filled with sterilized soil. The pots were buried 15 cm in the ground and covered with aluminum wire screen treated with a metal band. Field rearing studies were started during spring 1971 using 15 pairs containing pairs of *salinus* and 25 pairs containing pairs of

chilensis. Observations were made at intervals of 4-12 weeks. The soil from the pits was dumped into a plastic sheet (1.5 x 1.4 m) and examined for different stages of mole cricket. Dry dog food was placed in the pits after making the observations. Plants and grasses were allowed to grow in and outside the pits.

#### Results

With some exceptions, neither the field nor the laboratory rearing of mole crickets was successful. In the field, heavy rains (5-18 cm on 18 August 1973) flooded the rearing pits and killed the adults, and in the laboratory, the mole crickets died due to rapid desiccation of soil. The following summarizes the results of the laboratory work. For 20 gryllus females that laid eggs, the number of eggs varied from 7-21 ( $\bar{X} \pm 1.4 = 10 \pm 7$ ). G. sialis females laid similar numbers of eggs, 14-40 ( $\bar{X} \pm 1.6 = 20 \pm 10$ ). Some females of gryllus laid more than one batch of eggs. On 3 August 1973, I collected 18 eggs of gryllus in an egg chamber and by 3 weeks later the same female had laid 21 additional eggs in a second chamber. Similarly, I found within 10 days 3 egg chambers, each with 8-11 eggs, produced by a single female gryllus. Adults of gryllus that were collected in June and July 1973 laid eggs in July and August 1973. G. sialis adults collected in April and May 1973 laid their eggs in May, June, and July 1973. I never observed females of either gryllus or sialis attending their eggs as reported for Scaphiophaga humboldtii by Parry (Monthly 1944). The percent of hatching eggs of gryllus and sialis was 62 and 65 respectively. In one case, I reared a sialis from egg to adult. The parents were captured 3 April 1973, and the first generation adult was found 11 March 1974.

If the eggs were successfully reared in the field, I observed newly hatched nymphs during October 1972 in 3 pools. These nymphs were produced by 3 females of griseus captured 12 July 1972. These nymphs matured as early as the first week of April 1973. During my observation of field pools in winter (January and February 1973), I saw only nymphs with developing wing pads.

### Discussion

LIFE cycles of griseus and virgatus in Jacksonville, Florida, are not clearly understood. In my field research, adults found in early summer laid eggs in summer that produced adults the following spring; this indicates that some spring adults give rise to spring adults. However, the life cycle may not be as simple as this would indicate. The reason being, adults of griseus occur all months of the year, and periods of flight and winging were found in both spring and fall. I have collected flying griseus from 4 November 1972 to 2 January 1973 and 28 May to 16 July 1973. L. J. Walker (unpublished data) collected winging males of griseus around Jacksonville, Florida, weekly for more than a year at 12 sites and found adults every month.

With the available data, two models of griseus life history are worth considering. The first model suggests that the spring flying and winging population produces a small fall population and a major spring population. The progeny of the fall population becomes part of the spring population. The second model is based on the assumption that the fall and spring populations are discrete. In this model offspring of the spring population mature the following spring, and those of the fall population the following fall, with the possibility of an overwintering generation.

In the third model, early or early season adults of agelaius lay eggs in late spring or summer. The early hatched young have two types of development: some develop fast and become adults in fall, most develop slowly and become adults the following spring. The main consideration in agelaius life cycles concerns the fall population, especially when the fall adults mate and lay eggs. The different possibilities concerning such fall adults are summarized below:



I will analyze each of the above possibilities based on the current evidence. In crickets, the calling songs of males attract sexually responsive females and the males mate with the females (Alexander 1960). Singing of males is correlated with mating activities. Singing of agelaius in Bolinasville occurred during fall with a peak in October (D. J. Walker, unpublished data), suggesting that there is mating among fall adults. If mating occurs in fall, the main question is whether the mated (mated) adults lay eggs in fall or not. Recently (Dipol) and we find one egg laying many agelaius female agelaius during fall. If eggs are not laid in fall, is it possible for the mated female to store sperm in the spermathecae? D. J. Walker (unpublished data) reports that mated

families of Agelaius species can lay fertile eggs for at least two months without further ovulation. However, no evidence was known to delay self-pairing for a month or more following immigration. This raises a question: If eggs are laid in fall, do they hatch in fall or spring? The few life cycle studies of male ardeids suggest that the overwintering stages are only nymphs and adults, not eggs. Therefore, if eggs are laid in fall, they probably do not overwinter, but hatch that fall.

My second model proposes that the spring population of Agelaius lays eggs in late spring and summer, and that these eggs give rise to overwintering nymphs. Adults appear in spring or early summer from these nymphs. The fall adults lay eggs in fall that produce overwintering nymphs that become adults the following fall. The spring and fall populations are separated seasonally and do not interbreed in nature. If this model seems arbitrary, consider that the most common field ardeids of the northeastern United States (Agelaius phoeniceus, Alexander and Pipilo) and E. americanus (Dumetia) have comparably contrasting life cycles, and were long believed to be a single species.

In the case of Agelaius, I have circumstantial evidence suggesting that fall families do not lay eggs in fall. I collected 44 female Agelaius on 12 November 1972 near Brooktondale, Massachusetts and placed them in 4 pairs, 10 females in each pair. I kept these pairs outdoors at the Bump Pond Farm from 12 November 1972 to 15 April 1973. I found neither eggs nor nymphs after 3 months, but found 10 females. The absence of eggs or nymphs does not prove conclusively that the adults do not lay eggs in fall because one cannot exclude the possibility of cannibalism or that the females were sterile. Under the circumstances specified above, neither model suggested for Agelaius can be excluded for Agelaius. The

Life cycles could be understood by field rearing, especially of full adults, thereby confirming (or refuting) the models.

Knowledge of life cycles, especially the seasonal distribution of different stages of male crickets, would be very useful in suggesting effective control procedures. A systematic survey of a pasture for different stages of male crickets at weekly or shorter intervals would be useful, especially if correlated with rearing studies for psyllids and flies.



## CHAPTER 3 SOUND PRODUCTION IN MALE CRICKETS

Male cricket sounds, especially the male calling songs, are alluring to females. If one walks on an irrigated lawn during a spring or summer night, probably half an hour after sunset, he should hear the long-continued, musical trills of male crickets from the ground. E. rubiginos and gryllus calling songs can be distinguished by their trills. E. rubiginos has a bell-like trill, whereas gryllus has a loud-like trill.

Wiese and Hildebrand (1944) compared the male calling song of Gryllus latipes grylloides to "the cry of a cat or goat rather." The calling songs of male crickets have been used in systematics. Bennett-Clark (1950) identified a new species of French male cricket, E. rufinus, and reported that it differed from the European male cricket, E. grylloides, on the basis of calling song. The calling song of E. grylloides was "a quiet and jerky trill," with a carrier frequency of 3.5 kHz, while the song of E. rufinus was "a loud pleasing ringing, like an electric bell" with a carrier frequency of 3.5 kHz. Ross and Mountain (1951) reported that two dimensional forms of E. grylloides from Canada have distinctive calling songs, one with long trills and the other with abrupt. Bennett-Clark (1950) measured the frequency of a calling song of E. rufinus at various points and plotted an isobar diagram of the song. By using these data, he was able to calculate the acoustic energy emitted in sound production, and in E. rufinus, he estimated the efficiency of conversion of muscular power to acoustic power as about 11%. He discovered that chirping

S. pyralis and S. rufus had hourglass-shaped burrows with two entrances. Furthermore, he speculated that the slope of the burrows indicated the wind propagation.

Within most situations in which only males make sounds, female solo crevasses have been observed to produce sounds (Pomeroy-Smith and von Borke 1961, Baumgartner 1963). Baumgartner (1963) reported the call of a female S. hexalepis as a loud and distinct chirp. He observed females making these chirps when the individual was approaching another, especially when one was digging a new tunnel. Thiele (1968) described the sound of a capped female Australian solo cricket, S. sp. Thiele, as "bell pulsing sounds, clearly audible via foot song". The frequency of female sound production is unknown.

### Methods

All of observations were made within 15 miles of Belmarville, Florida, from 1968 to 1974. Recordings of male cricket songs were made with a portable tape recorder (Rego 111<sup>00</sup>, RadioShack, Pompano Beach, Section 1-40) and a microphone (Electro-Voice<sup>60</sup>, Model 600C), mounted on a camera tripod directly downward over the entrance of the solo cricket burrow and 15-25 cm above the ground (Fig. 3.1). The calling songs of g. latius ( $n = 70$ ) and g. rufus ( $n = 40$ ) were tape recorded in the field. The following weather factors were recorded about the tape recordings: soil and air temperatures, relative humidity, and light intensity. Soil temperatures were taken 3-6 cm deep, near (within 15 cm) the entrance of the solo cricket's burrow. Air temperature was recorded 1.5 m above the ground level. Relative humidity was measured with a psychrometer.

Decca Model No. 350) 1 m above the ground. A light meter (Photovolt Corporation Model No. 344) was used to measure the light intensity. The light-intensity target was aimed directly upward. The sunset time was calculated for Delmarville by using the World Almanac (Long 1980). The time of singing was recorded in Eastern Standard Time which was verified daily before going to the field. The features of male cricket calling songs (i.e. duration, carrier frequency, and pulse rate) were measured in two ways. The intensity of the calling song was measured in the field, 15 m above the bottom antenna, using a sound level meter (General Radio Model No. 1551-1, weighting factor A, reference intensity =  $0.0002 \text{ dynes/cm}^2$ ). Carrier frequency and pulse rate were analysed with a frequency (Ray Electronics Co.).

The starting times of male cricket calling songs were recorded in the field. As soon as I heard the first calling songs of spizoid and rhizoid, I started the time. If the first calling song was not followed by two other calling songs of the same species within 3 minutes, I discarded the previously noted [start/stop] time.

The effects of weather factors on the different parameters of male calling songs in spizoid and rhizoid were examined using the method of least squares for fitting a multiple regression model (Sear et al. 1974), based on a straight line equation,  $y = a_0 + b_1x_1 + b_2x_2 + b_3x_3$ , where  $y$  = estimated or predicted value of a parameter of calling song (e.g., intensity, carrier frequency, and pulse rate),  $a_0$  = constant,  $b_1, \dots, b_3$  = the estimate or measure of the strength or the effect of  $x_1, \dots, x_3$  on the response  $y$ ,  $x_1, \dots, x_3$  = the independent variables (i.e. weather factors— soil temperature, air temperature, and relative humidity).

## Results and Discussion

Sound production in crickets is generally by sequential articulation. There is a stopper on the anterior portion of the lower margin of each forewing and there is a striated-silky file on the inner surface of each male forewing. The sound is produced when the stopper of one wing rubs against the file of the other. It is difficult to make observations of singing male crickets because they are in the soil. It appears that the sound production in gryllus and gryllus is similar to other crickets. In one occasion, I observed a male gryllus producing the calling song in a plastic box without any soil. The wings were moving rapidly and were raised about 45-50° above the thorax. The left wing was near the right wing (similar what has been reported for other crickets).

The calling songs of gryllus can be heard near the borders of ponds and lakes, on the sides of streams, meadows, fields, and forests. gryllus songs were heard mostly in forests, meadows, and usually filled fields.

Calling songs in gryllus and gryllus are produced in their habitats in the absence of other members of the same species. With some exceptions, gryllus and gryllus have calling after sunset (Table 1.1). During and after rain, I have heard calling songs of gryllus and gryllus at all times of night. I have never heard calling songs of gryllus during any light hours prior to sunset. Except on one occasion (Table 1.1 Forests), gryllus calling songs were heard only after sunset. In most cases, the light intensity was less than 4% lux when calling songs started. The notes of gryllus and gryllus song for 1-4 to 1-6 hours nearly continuous early. The singing was interrupted continuously by silent periods varying from 2 seconds to 5 minutes.

Prior to the commencement of singing, the males of gibbosus and plumbeus use an entrance to their burrow. The entrance is made smooth with the male's tail and wings. After working on the burrow entrance, he looks into the burrow, turns around, and starts singing with his abdomen towards the entrance. Males start their songs with short trills of 2-3 notes. Sometimes they sing singing, turn around, and return to smoothing the entrance. In this manner the female calls are made very smooth. Of 18 captured gibbosus observed for singing in the field, 4 started their entrance after singing. When such was the case, the entrance hole on the following evening was often in a new position.

The different parameters of male calling songs of gibbosus and plumbeus are given in Table 3.2. The distribution of carrier frequency of the calling songs of gibbosus and plumbeus is shown in Fig. 3.29. The modal frequency of gibbosus and plumbeus was 3.2 kHz and 3.8 kHz respectively ( $P < 0.05$ ). The pulse rates of gibbosus and plumbeus are dramatically different in the calling songs (Fig. 3.30a and 3.30b).

Regression analysis of the effect of weather factors on the different parameters of male calling songs revealed no correlation between temperature (soil and air) or relative humidity and intensity or carrier frequency of the calling songs of either gibbosus or plumbeus ( $P > 0.05$ ). The pulse rate of gibbosus was found to be a function of soil temperature (Fig. 3.44).

No correlation existed between pulse rate and air temperature or relative humidity ( $P > 0.05$ ). I have never heard the calling songs of gibbosus and plumbeus below 18°C, in spite of being in the field during cold, but otherwise appropriate, nights.

In addition to the soil temperature, soil moisture was found to

collected the production of calling songs by glaucus and viridis from page 152. In an unlighted enclosure from 20-21 May 1971, 4 plots (30 x 2') were marked. I randomly selected 2 of these and irrigated them with overhead sprinklers for half an hour during their night. The other 2 plots were left unirrigated. There was no rain during the period when I conducted the experiment. After 24 hours, I found 2 glaucus and 10 viridis males staying in the irrigated plots, and none in the unirrigated area.

In addition to the calling songs, males of glaucus and viridis produce two other kinds of songs--aggressive songs and courtship songs (Fig. 3-4). The aggressive song is produced in the presence of another male. When a male encounters another male, short trills are produced intermittently. In two specimens, I have observed aggressive singing of glaucus in a plastic box. The songs are raised 10-20" above the thorax. (as in calling) and usually do my observation of calling, I saw the right wing above the left wing. After the short trills, the males pushed each other with their distal scutella. I could not detect any difference in the aggressive songs of a single viridis or the presence of a single male glaucus or a single male glaucus (Fig. 3-5A, B).

Males of glaucus and viridis use a characteristic courtship song in the presence of females. A single male in the presence of a single female produces the courtship song intermittently from 15 minutes to 1 day. I have heard courtship songs of glaucus in the field at all times of the day (Fig. 3-6). The courtship songs of glaucus and viridis are rhythmic sequences of short trills, produced intermittently. The carrier frequency and pulse rates of these songs are similar to calling. The courtship song of glaucus has two phrases: the beginning phrase of the

long is a long sequence of notes (Fig. 3-3a). This is followed by a sequence of short notes (Fig. 3-3b).

In addition to the note songs (calling, aggression, and greeting), I heard females of gigana producing short bursts of sound (Fig. 3-3d). I called this song. On 8 March 1974, I collected 10 females of gigana on broadcasting systems and kept them in a plastic box with 8 cm of moist soil covered with 2 edge paper towels. During the same night I heard dull and short bursts of sound from the plastic box. I saw two female gigana facing each other on the surface of the paper towels. One of the females raised its wings. During the lateral movement of the wings (same as calling notes), a dull sound was produced. The female gave two ultrasonic energy frequencies varying from 3 to 4 kHz, unlike the note sounds which have most of their energy at 3.5-5 kHz. The pulse rates vary from 14 to 12 per second compared to 110 in note calling. The pulses are in groups of short duration as in variable songs.

CHAPTER 4. (HYPOTHESIS 4)  
PREDATORS OF INSECTS IN FLIGHT

Spiders, Insect-Flies of Hole and Female Hole Crickets  
in the Hymenoptera (Chilopoda, Scolytidae)

Phonotaxis is movement oriented to reflection of sound. In crickets and katydids, males produce species-specific calling songs that attract sexually receptive females to them (Alexander 1962). Generally, females move to the calling males either by walking or running.

While I was observing male crickets flight at a lighted golf course near Gainesville, Florida, in spring 1970, I saw a female gryllus land near a burrow entrance where a male gryllus was singing. The female ran to the male burrow and entered. I thought the male gryllus had attracted the female by his calling song. I tested the hypothesis that flying females were attracted to singing males with a simple experiment on 15 April 1970 (Fig. 4-1). The female gryllus landed near a singing male as compared to one that landed on the standard. The standard had no calling males. After I had confirmed that flying females were attracted to calling males, I wanted to prove that the flying females were attracted only to the sound of the singing male as opposed to other ingredients (e.g., male pheromone or infrared radiation from the genitalia). To test my theory, I broadcast a natural calling song of gryllus through an amplifier and a speaker on 11 April 1970. I collected 30 gryllus (8 males) in a 3 m<sup>2</sup> area in 15 minutes. Similarly, I captured 40 gryllus (8 males) and 4 gryllus on 24 April 1970 when I broadcast the natural



gliding calling song. The male crickets that flew to the broadcasting speaker were not only females, but also included males.

In preliminary experiments, flying adults of both sexes were attracted to a broadcast sound of a male solo cricket. Orientation to sound occurred in flight. This was the first demonstration of an orthotaxic response to sound during flight.

I conducted further experiments at a lighted golf course (State Highway No. 16, Section 26 of Township 4 N, R. 7E, 16 km west of Gainesville, Florida) in 1955 and an adjacent field (Gaines State Park, Department of Agronomy, University of Florida, State Highway No. 16, Section 27 of Township 4 N, R. 7E, 16 km northwest of Gainesville) in 1957.

This chapter has two sections. The present section describes my experiments relating to the spatial-sensitivity of flying gliding and gliding with the two-recorded natural male calling songs as well as synthetic sounds simulating the natural calling songs. The next section (D) describes the response of male crickets to different parameters of synthetic songs.

### Methods

My experimental system consisted of two independent broadcast systems and 2 large metal funnels (1.2 m diameter). Each broadcast system included battery operated tape recorder (Rega III and IV), a battery operated radioamplifier (Aqua Electronics) and a loudspeaker (Boschella Model No. 40-1111 covered with aluminum screen). Tape recorders and radioamplifiers were housed in a plastic wagon (Fig. 4-22). Each speaker was mounted in the center of a funnel and was aimed upward

(Fig. 4.19). Pupae were placed 3-20 cm apart (Fig. 4.20). The adults that flew into a funnel (Fig. 4.18) were collected in a numbered (20) of jar, attached to a jar ring attached to the bottom of the funnel.

The natural calling songs of gigantes and gigantes were been recorded in the field at 15°C (page 10). The term "natural song" will refer to the taped natural calling songs. Synthetic calling songs were made and then recorded in the laboratory. Synthetic male artificial calling songs were produced with electronically equipment described in Page (1974). During electronic synthesis of songs, the pulse duration/pulse interval ratio of the song was maintained at 1:1. The actual ratio of pulse duration to pulse interval is 3 songs (15°C) of gigantes was 2:1, and that of gigantes was 1:1. Therefore, the term "synthetic song" will refer to the taped electronic imitation of male artificial calling songs. All the synthetic songs were checked for accuracy of pulse rate and carrier frequency.

Broadcasting trials began 15 minutes after sunset and continued until most flights ended or have later. During each trial, gigantes and gigantes calls were broadcast simultaneously and a trial was stopped when at least one of the (20) of jars contained 20 or more male crickets. Tests were made only when the soil temperature was  $15 \pm 1^\circ\text{C}$ . Soil temperature was recorded at 4-6 places near the traps. A predetermined deviation was not used for each trial because the number of male crickets flying varied greatly at different seasons, dates, and times (Fig. 5.1, 5.2). Trials in which no jar yielded as many as 20 male crickets were disregarded. The jars with trapped male crickets were detached from the funnels after each trial and replaced with empty ones.

The speaker first used to broadcast a particular song was selected

by using a random number table. In subsequent trials of the same pair of songs, the speaker's song was alternated in order to negate position effects. During each trial the third female served as a control. At the end of each evening's trials, the male crickets in each numbered jar were identified (i.e., as gambelii or chrysops), counted, and mass feeding was done on the basis of a black spot on the dorsal side of the male forewings--females lack this spot.

To determine whether the females attracted to the broadcast sound were male or not, I recorded 10 gambelii and 10 chrysops for sperm in the spermathecae. On more than 5 occasions, separated by a week or more, I exposed 10 to 20 females that flew into the funnels. These females were immediately placed in containers apart from males. The spermatheca was dissected out, squashed with a drop of water under a cover slip, and examined (light magnification) for sperm.

The sex ratios of gambelii adults that flew into the funnels were compared with those of adults that landed outside the funnels.

### Results

At the Lighted-Self Course, male crickets could be seen flying near the lights 100 m from the funnels. When broadcasting began, some of these altered direction and flew towards the funnels. At the unlit-past-Self-Side Course, the flying male crickets could be seen only as they passed the funnels. At both sites, many male crickets dropped or flew into the funnels. Others landed on the soil nearby. Twenty to 50 percent of the recorded male crickets landed outside the funnel. Those adults which landed outside the funnel ran in all directions, some of them ran towards the source of the sound (i.e., under the funnel), some of them moved away from the funnel, but all eventually burrowed into the soil. In

Female crickets and males, I have trapped as many as 150 male crickets per minute at a broadcast point. Attraction of male crickets to broadcast sounds at the Lighted Golf Course and at the welllighted Brown Horse Park was similar.

I carried out 15 trials with natural songs of both gigantes and viridis. In a total broadcasting duration of 124 minutes, I trapped 115 males. Of gigantes and viridis were principally attracted to their own songs (Fig. 4-10). I conducted 15 additional trials with taped synthetic songs for a total of 22 minutes and trapped 887 males. These results were similar to those with natural sounds (Fig. 4-10).

Results of trials with synthetic calling songs suggest that carrier frequency and pulse rates of male calling songs may be the important code for a flying male cricket making a species-specific response. Ten percent of gigantes females were trapped at gigantes songs and 1/40 of viridis females were attracted to gigantes songs. A significantly higher proportion of gigantes females was attracted to gigantes songs than vice versa ( $P < 0.01$ ). For each species, with both natural and synthetic songs, a larger proportion of females than males showed species-specific responses.

In both gigantes and viridis, I found more mated females than unmated ones. Of 26 gigantes females examined, 311 had sperm in the spermatheca and I found that 54 of 83 female viridis had sperm. Percent of females that had sperm in the spermatheca was found to increase as the male cricket flight season progressed (Fig. 4-4).

While I was broadcasting calling songs of male crickets, I collected males and females of a few crickets other than male crickets in the female (scent) trap. These crickets did not come in either the songed or gigantes cases. Although the three species of crickets captured repre-

tested these individuals, their calling songs were similar to that of agelaius (Table 4-1). The calling songs of all of these were similar with pulse rates at 20°C within 10 pulses per second of agelaius (Table 4-1). In two instances, I broadcast the calling songs of trichas rubens and agelaius simultaneously. In trichas responded to its own male calling song (Table 4-2). The females of E. gambelii ( $n = 3$ ) had none in the summer chosen.

### Discussion

The attraction of virgin female arthropods to male calling songs is easily understood. The attraction of females with sperm in their spermathecae and especially the attraction of males are less easily interpreted. The flights of these individuals (chocked virgin females) could be interpreted as dispersive flights. The flying adults might use the sound signaling of males of their species as an indication of a habitat suitable for colonization.

Two kinds of experiments were conducted to test a hypothesis that the male arthropods use the sound signaling of males as a habitat indicating signal. The first aim was to observe the calling male and to record the number and sex of the male arthropods landing near the entrance of the burrow. One would predict that the adults flying towards the sound of a male indicating signal would land near the male burrow and those flying toward it as a habitat indicating signal would land farther away. Therefore, those landing around the entrance of the male burrow should include a significantly higher proportion of females than those landing farther away from the burrow. In two instances, I sat near the entrance of a male burrow and counted the adults landing within 0.5 m of the burrow.

the female gullies. One or more birds landed within short distances of a calling male gullies on 15 April 1955. I collected 3 female gullies (but no males) landing within 10 m of a male gullies between 8 March 1956.

In the second test I collected the adults that were landing outside the mixed loop during the brood-raising trials. I compared the sex ratio (SR) of 1000 gullies (SR,  $\hat{\theta} = 0.007$ ) that had landed inside the loop with that of 1000 that had landed outside (SR,  $\hat{\theta} = 0.114$ ) and found significant difference ( $p = 0.01$ ). These two experiments support the hypothesis that male white crickets use the calling song as a sign of suitable habitat.

Stearns (1955) demonstrated that male *crickets* *crickets* were attracted to male calling songs, however, the animal was radiorecording aggression over the occupation of territory or brooding space. Aggressive aggression occurs in *crickets* and has been studied and described, but the approach of cricket males to male calling songs has not been reported (Alexander 1961). I have never observed it in male *crickets*.

## CHAPTER 4 (Section 4) PREDATORS OF SOLE CRICKETS IN FLIGHT

### Reaction of Flying Male Crickets to Different Parameters of Acoustic Signature Songs

In the previous section, I have shown that large numbers of sole crickets could be attracted to broadcast male calling songs in open fields. This technique of attracting flying crickets to loudspeakers might prove useful in control of sole crickets—either as a means of destroying crickets or as a means of using control procedures. Steps would now be taken for the control of sole crickets, parameters of calling songs that were responsible for the attraction were investigated.

Miller (1960) demonstrated that female lone crickets, Euphonia, gigantea L. Miller, were able to discriminate the pulse rates of synthetic calling songs. Bennett-Clark and Selig (1961) showed that pulse rate was a critical parameter in the courtship song of Scotophilus. Bennett-Clark (1961) measured the biological significance of intensity in the courtship song of Scotophilus. Neurophysiologists have shown that auditory systems of crickets have different thresholds of hearing for different frequencies (e.g., Branson et al. 1964). All the above studies were carried out under laboratory conditions. Selig and his associates (1963), working with a locust, Eutettix sp., outdoors, found that the females responded to all kinds of synthetic signals—any sound that began strongly worked

Here I describe my experiments with *Lythys* using synthetically varied as well as live frequency, pulse rate, and intensity, at the request of Wright.

### Methods

The experiments were carried out at  $15 \pm 4^\circ\text{C}$  cell temperatures,  $25 \pm 5^\circ\text{C}$  air temperatures, and relative humidities of  $70 \pm 30\%$ . The experimental equipment and techniques were similar to those in Section 4 A. However, the following modifications were made. I used three independent broadcast systems and each was consisted of a portable tape recorder (Bell and Howell Model No. 204 and Sony Model No. TC-66 instead of tapes III and IV), an amplifier, and a speaker. A fourth female without a speaker served as a control. The synthetic sounds used throughout the experiments had an intensity of  $100 \pm 4\text{ dB}$  except in experiments where intensity was the parameter tested. In intensity experiments, I regulated the intensities  $\pm 1\text{ dB}$ . The actual calling songs of Lythys and phlyps varied from 92 to 103 dB (Table 3.1). These sounds were broadcast simultaneously, two call sounds and a standard sound. The standard sound was a synthetic song which had 4.8 kHz and 40 pulses per second (pps) for 102 and 2.7 kHz and 50 pps for 103. The latter standard closely approximated the natural song of SPC (Fig. 3.1, 3.4). The number of male crickets trapped on a song sound was compared with the number of crickets caught at the standard sound to calculate the relative response. Trials with less than 10 crickets in the standard were discarded. Each synthetic song was lasted on an length ten nights.



### Results

2. *g<sub>1</sub> calls* responded to the standard sound in the three greater numbers than to a continuous tone of the same frequency. Two limited stimuli (g<sub>1</sub>1000) were captured when the standard was used, as compared to 17 with the continuous tone (4 T and). Results of these trials ( $n = 4$ ) suggested that amplitude modulations are important to the responses to the calling songs. Since 22 flies in the continuous tone while none flew to the control, it is clear that transients are not essential features for the phonotaxis of flying g<sub>1</sub>1000. The number of trapped male crickets was a function of frequency and pulse rate (Fig. 4.4). Trials ( $n = 11$ ) in which intensity was the parameter varied trapped 100% males. The number of g<sub>1</sub>1000 trapped approximately doubled for every 4 dB increase up to 106 dB (Fig. 4.5). The control trap generally caught no male crickets and it never had more than 1 (4) of the number of males in the other three traps.

### Discussion

Several features of male calling songs have been suggested to elicit species-specific responses in crickets. In the case of male crickets, Bennett-Clark (1938) speculated that carrier frequency might be important to flying females. My data demonstrate that carrier frequency and pulse rate are important to species-specific phonotaxis in g<sub>1</sub>1000.

3. *g<sub>1</sub>1000* would be able to separate its own songs from g<sub>1</sub>1000 songs by pulse rate (Fig. 4.5). There are crickets, other than g<sub>1</sub>1000, occurring in the same habitat with pulse rates overlapping those of g<sub>1</sub>1000 calls (Table 4.2). Flying g<sub>1</sub>1000 is able to distinguish the songs of its own males from the songs of these other crickets by carrier frequency (Fig. 4.5).

The number of crickets trapped was approximately doubled for each 4 db increase. A simple logarithmic fits these data. The sound waves are radiating in all directions from the broadcasting loudspeakers. In general, the sound pressure is halved for each doubling of distance from a sound source. This change is usually measured as a decrease in sound pressure level of 6 db. I do not know the exact shape of the sound field around a broadcasting loudspeaker, but if you imagine the sound field produced by the broadcasting loudspeaker to resemble the crown of a tree, then the low intensity sound field would be similar to the crown of a small tree and the high intensity sound field would be similar to the crown of a big tree of the same proportion. According to the principle involved in sound pressure, the diameter of the crown of a tree would be doubled for each 6 db increase in intensity. If you assume that the only crickets are flying in a plane and radiating along straight vectors, you would expect the number of male crickets to double for every doubling of diameter.

## CHAPTER 5. DISPERSED FLIGHTS IN WOLF CRickets

WOLF crickets fly in large numbers under street lights at some nights during spring and fall in Florida, but little is known about the flights. Barnett (1961) reported that gigantes in Florida were observed in flight from 7 to 10 pm, in addition to bellied toads. Bush and Scherer (1941) collected gigantes and gigantes at light traps in Tifton, Georgia, from 1 April to 28 October 1940. They trapped 55 gigantes, 30 gigantes, and 3 gigantes. During the first half of the trapping period, their collections were 50% gigantes and in the last half they were 80% gigantes. Saville (1944) found that gigantes and gigantes flights occurred chiefly after dark and lasted about an hour. He stated that gigantes and gigantes flew in spring and fall and that gigantes was predominant in fall.

In this chapter, I describe the dispersed flights of gigantes and gigantes with special reference to duration, sex ratio, behavior, physiology, flight, and air speed.

### Methods

I made observations on wolf cricket flight daily, except on rainy or cold days < 18°C from 10 April to 31 July 1958, and from 22 February to 31 July 1959. I went to the field from 1 November 1958 to 1 February 1959 on those nights when the air temperature exceeded 18°C. I conducted all my experiments at the Lighted Golf Course and Green Hope Farm. Weather data were collected (see page 11). I monitored the flying

male crickets in the cage. My first method was to record all the male crickets that flew to the broadcasting loudspeakers on a night. My second procedure was to pick up after 10 pm the male crickets that had flown to street lights at 5 locations in and around downtown Los Angeles collected under the lights and all broadcast sound were identified, sexed, and counted.

I studied the starting time of male cricket flight and the variation in the number of flying males during a night by broadcasting. To record the starting time of male cricket flight, I broadcast the calling songs of gigitus and gigitus immediately after sunset. As soon as 3 or more adults had flown into the funnel, I considered the flight to have begun. To observe the fluctuations of the flying population during an evening, I removed adults from the sound trap at 5 minute intervals.

The air speed of flying gigitus ( $\bar{x} = 10$ ) was observed at the Bell Center on 3 June 1973. The method was similar to that of Holmgren (1969).

An attempt was made to study the wing-beat frequency of flying male crickets and temperature of thoracic muscles in the flying adults. A flight mill similar to that of Shattuck and Holmgren (1969) was used to study the wing-beat frequency of male crickets. Seven gigitus collected (28 April 1973) were tested on the flight mill 1 May 1973. In timing the duration of the flight, I disrupted pieces of 15 seconds or less. Wing-beat frequency was measured with a stereoscopic light microscope, General Radio Model 420C. The thoracic temperature of flying crickets was measured within 30 seconds after they had stopped flying. I placed the mesothorax of the adult with a needle containing a thermocouple and measured the temperature with a Bellco Instrument Co Model BAC-4 analyzer. At the Bell Center, I made measurements of

characteristic responses of female agitated within 30 seconds of their landing.

Catching, releasing, and monitoring of agitated was carried out from May to July 1974 at the Green Lake Park in Flint mi; whether individuals flew over that area and the distance flown. Flying adults (> 3000) were released at broadcasting loudspeakers. I used different colors of acrylic paint to mark different portions of the pronotum to indicate the date, distance, and direction of release. A total of 186 marked agitated (PSS males) were released in various directions. Catching, marking, and releasing of adults were carried out on the same night. I placed the adults (in groups of 10) in paper cups (10 cm x 5 cm height) during the retrieval because capture and release to avoid cannibalism or injury to the adults. On a given night, I released the adults at a single distance from a center point, but in various directions. Recapturing was at the center point by broadcasting synthetic songs of agitated. Adults that landed inside the funnel were marked for marks with a portable 10 light (Globe Light Products Inc. Model 99L-10). The marks were clearly distinguishable by their brilliant fluorescence. The recaptured (i.e. previously marked) adults were marked distinguishably and released at the same night from the same distance and direction that they had been previously released.

I tested a hypothesis that male deliberate fly through or above forests. I conducted the experiments in two situations using the broadcasting technique. In the first one, I released an area (100 x 100 m), covered with pine and oak trees (3-10 m high) between two open fields on 22 April 1974. I placed a sound trap at the midpoint of the woods and also in the open field and broadcast deliberate songs for 16 minutes. In the other situation (24 May 1974), I broadcast deliberate and agitated

some on the roof of Bakery Hall (formerly of Florida Hospital), a kitchenery building surrounded by trees and weeds.

### RESULTS

In Jacksonville, Florida, there are two flights of agelaius and glaucope, a major spring flight and a minor fall flight. I captured a total of 943 adults of which 551 were agelaius during spring 1952, whereas 155 adults 144 glaucope were collected in fall 1953. With a few exceptions, the flight activities of agelaius and glaucope are largely seasonally separated (Fig. 3-5C). During 1952, agelaius flew from May to July, and glaucope flew from March to May. In 1953 between during 1952 and 1953, agelaius and glaucope flew to large numbers ( $n = 44$ ) on the same night. I have noticed a few adults of both species flying other months. For instance, I have collected agelaius ( $n = 5$  per night) adults in March and April when agelaius flew predominantly. Similarly, glaucope ( $n = 5$  per night) adults were trapped in July when agelaius was predominant. Fall flights occurred on 4, 7, 11, and 12 November, 3, 4, 7, and 8 December, and 2 January 1953. I collected 31 agelaius and 162 glaucope in these 9 days. Of those collected in November ( $n = 34$ ), 541 were agelaius. Of those captured in December and January ( $n = 144$ ), 551 were glaucope.

Surveys of observations (except 21 May 1952), the number of flying females was consistently more than the number of males. I collected 541 agelaius and 751 glaucope adults during 1952 and 1953. Of these, 852 were females in both species. Sex ratios of agelaius and glaucope from two sampling techniques are given in Fig. 3-6. Sex ratios of agelaius collected under light and sound are not significantly different from each other ( $\chi^2 = 0.050$ ), while the sex ratio of glaucope collected under light was significantly different from the sex ratio of (glaucope) adults trapped by the sound ( $\chi^2 = 8.081$ ).

Flight activities started immediately after sunset (Table 3.4) and continued for at least 17h 15p. Adults of gibbosus and virgatus emerged from the ground. I observed gibbosus adults on the surface of the soil soon after sunset. Most of the gibbosus observed did not come out of the ground until it became dark (light intensity <100 lux). A few came to the surface soon after sunset.

Some of the gibbosus and virgatus in the soil raised their legs and moved them rapidly. The movements were similar to those observed during insect production (legs moved frequently), but often-- in gibbosus, the legs were moving fast while the hind and front legs were kept close to the body. The metathoracic legs were kept wide apart. In addition to the movement of the legs, the body was also vibrating. Probably some crickets raise their body temperature before take-off.

Take-off was not closely observed in gibbosus, but in virgatus the head and front portions of the body were raised, keeping the front legs close to the head, and the body was pushed into the air by the hind legs. Sometimes virgatus made small jumps ranging from 15 cm to 30 cm for several times before it took off. In some cases, I saw virgatus and gibbosus making short flights of 0.5-1m.

I have observed landing of both species in the presence or absence of brightness. I could not detect any differences in the landing behavior of gibbosus and virgatus. Landing occurred in several patterns at the Self Course in the absence of brightness. Some adults landed on the ground exactly like aircraft, then abruptly crashed to earth. After landing, I observed, some crickets did one of three things--some (three females) entered a male's burrow, most of the rest dug into the soil, and some flew again.

Mean wingbeat frequency of captured female *A. obscura* was 446 Hz at 25 °C (air) and full relative humidity. One female flew 42 minutes on the flight mill (Table 3.13). There is no correlation between the duration of flight and the thoracic temperature of the tethered females. The mean thoracic temperatures, recorded from the flying gleaning subjects, was 4°C above the ambient (air) temperature ( $28 \pm 4.5^\circ$ , range,  $\pm 0.2 - 37^\circ$ ) (Table 3.12).

In the dispersed studies, 26 of marked gleaners were recaptured (1.6 flies each then one night) (Fig. 3.44). These adults flew more than one night (Fig. 3.45). The minimum duration between the release of a marked adult and recapture of the same individual was 6 weeks, proving that some adults fly again during a period of 6 weeks. Some individuals flew about a kilometer (Fig. 3.46). The air speed of gleaners varied from 3.2 to 18 metres ( $\bar{x} \pm SE = 11.8 \pm 1.1$  m/s) on a clear night with no wind.

The results of experiments designed to see whether male *A. obscura* could fly through and above woods were positive. I collected 100 gleaners in the wood trap in the middle of the woods and 158 gleaners in the trap in the open field. In one occasion I saw 160 fly flying adults while walking through the woods during broadcasting. I collected 10 gleaners and 40 gleaners on top of McCarry Hall, a three-storey building. This suggests that at least some adults fly over heights 30 m high.

### Observation

Male crickets occupy temporary habitats, and therefore flight is attractive to individuals. The factors causing the male crickets to fly are unknown. Reluctance of feet, crowding of individuals with multiple disjunctives, and physical obstruction of habitat might cause the adults



to fly. It appears that proper climatic conditions are necessary for the flight. I have never seen gliding or gliding fly below 10° Celsius and also. For instance, gliding flight did not occur from 18 March to 30 March 1955 and from 1 April to 12 April 1955 due to cold (soft) temperature < 10°C and a few rainy days. Although present at the highest self source during a few cold nights, I failed to see flying male crickets. On many occasions I observed large numbers of flying male crickets after the rains, especially after a long dry period. Rain is one of the important factors determining male cricket flight.

It seems that presence of proper atmospheric scope (e.g., recently released adults) might influence the male cricket flight (see page 8 or 9). It appears that there were two peaks of flight for gliding during 1955 (Fig. 3-10). The first peak (3 March 1955) was probably due to the manufacturing adults that started flying after the warm weather. The second peak (20 April 1955) might be due to the new adults that developed from overwintering adults. In Puerto Rico, gliding flies from October to December (see Sakaguchi, 1958), but the major flight in Hawaii is observed during March to May 1955. I was not able to monitor gliding flight during 1955.

It is not known what cues are used by male crickets to start their flight on an evening. Light intensity might play a role. I have never seen male crickets fly at a light intensity more than 45 lux. I found the flight of gliding occurring after the flight of gliding (Table 3-3, Fig. 3-9). Similarly, response of gliding started after gliding started their sleep (Table 3-1). Lloyd (1944, 1945) and Farnsworth (1950) observed that fireflies, gliding species, flew at a speed faster than during night.

Physiological studies on energy expenditure and source of fuel used

lar flight are some of the areas that would help to elucidate hole cricket flight.

Stagnant weather suggest that reorientation of a localized field would occur several times in the same season. Hole crickets fly from one field to another. It seems that a windfall around a field would not prevent its colonization. Hole crickets could fly either through or above the canopy. Recolonization of treated golf courses, even though they are not flighted, would occur from a nearby infected property.

Unless the hole cricket flight is clearly understood, control procedures may prove ineffective.

## CHAPTER 4 FEED HABITS OF NOLE CRICKETS

Numerous reports describe mole cricket damage to a variety of crops. Rayette (1944) pointed out that the damage caused to the plants was of two sorts: (I) direct damage of plants by feeding on stems or roots, (II) indirect damage by uprooting the plants. Hunsaker (1960) reported that the use of girdling reduced plant materials and soil particles. He did not mention how many crops were mentioned or their source. Only a limited amount of information is available on the feed habits of other mole crickets (Davis 1961, 1964, 1965; Lehrer 1965).

This chapter describes by attempt to get direct quantitative evidence on the feed habits of mole crickets in the field.

### Methods

I captured the crop contents of (I) adult scyllarus and (II) adult gryllotalpa. Adults were classified as flying and nonflying. Flying adults had flown into wood crops. Nonflying adults were either crawling under or burrowing into the surface of the soil during a rainy day. The captured mole crickets were dissected within 2 hours and contents of the crop were examined.

### Results and Discussion

Crops of scyllarus and gryllotalpa had various plant materials (e.g., roots, stems, and leaves, grass blades) and insect parts (e.g., cater-

cuticle, numerous, coarse, long. Of 20 gryllids having food in the crop, 11 had insect parts, 1 had plant materials, 2 had both, and in the rest the material could not be identified.

The unidentified material was a soft, white, dark brown substance. Of 19 gryllids having food in the crop, 3 had insect parts, 10 had plant material, 4 had both, and 2 had only unidentified material. I realized that 90% of the flying adults had every crop distended with gas (Stable 8.14). On these occasions, I found nematodes belonging to the family Therapanthidae (e. g. *R. trilinea* (personal communication)) did not consider these nematodes (probably genus gryllids, Kaur 1964) would be pathogenic to male crickets.

On two occasions I have seen cannibalism. Once I saw a captive female gryllid devouring a newly hatched nymph. Another time I found a partly eaten Holey adult gryllid when I kept more than 10 adults in a plastic box overnight.

My observations suggest that food storage may occur in male crickets. Under laboratory conditions, I kept a gryllid in a plastic cup (12 cm diameter x 14 cm height) for more than a week and placed 1500 wheat kernels on the surface of the soil. I found a few wheat kernels at the bottom of the cup in an oval cluster.

CHAPTER 2  
OTHER ASPECTS OF BEHAVIOR

Very little information is available on the burrowing habits of male arribas. In gobionus and maculatus burrows deep (about 1 m) into the soil (Smith 1936 - 1938, 1953) did not find any surface burrowing below 10°C. Boring behavior in gryllariensis (Moldave 1955) and in S. hammondiensis (Huangman 1969, Alexander and Soto 1971) has been described. Courtship and mating behavior is unknown in hammondiensis species.

Here I report my observations with reference to (a) spatial patterns found in gobionus and gryllariensis burrows, (b) courtship behavior, and (c) effects of insecticides on male arribas.

Methods

Burrows of gobionus and gryllariensis were observed in the laboratory. I mounted the burrows in the rearing containers by cutting the soil vertically from side to side with a knife. Digging of soil facilitated finding spatial patterns of the arribas. I applied the burrows of digging noted in the field. Excavation of male burrows were made with a mixture of 50 g of (Kartar's) household cement and 100 ml of acetone.

On 28 April 1971, I observed the courtship behavior of gryllariensis for 2 hours in the laboratory. A male and a marked female were confined in a transparent plastic box with 3 cm of moist soil. Observations were made through the bottom of the container that was placed in an aluminum

particles. Similarly as these insects, I observed the similarly behavior in gibbosa for 15 minutes each.

An insecticide test was carried out in a potter's to test the efficiency of three chemical baits (Diazinon, Fenitrothion, and Dieldrin) on male crickets. I selected 12 plots ( $5 \text{ m}^2$  each) separated by 1 m border. The treatments of baits and control (no bait) were randomized and replicated 3 times. I irrigated the plots for 3 days before applying the baits (1.7 kg active ingredient per hectare) on 15 September 1981. The dead male crickets were counted on the surface of the soil for 4 days early in the morning (before 7 am). On 20 September, I dropped an area of  $1 \text{ m}^2$  in each plot with 10 cylinders to sample the male cricket population in the treated and control plots. I counted the male crickets that emerged from the soil within 15 minutes. In the same date, I observed the efficiency of bacterial bait mixtures in 4 pots ( $0.4 \text{ m}$  diameter) with about barrels at feed. The bait (0.1 kg active ingredient per hectare) was applied on the surface of the pots. The fourth was a control. Each pot had 3 large spoons of gibbosa.

### Results

I found typical egg chambers in the rearing containers. In gibbosa and gibbosa constructed cylindrical chambers and laid their eggs in these cells. The egg chambers of gibbosa ( $n = 11$ ) varied in their length from 2.4 to 4.3 cm ( $\bar{X} \pm SE = 3.36 \pm 0.79$  cm) and in their width at widest point from 1.2 to 1.6 cm ( $\bar{X} \pm SE = 1.33 \pm 0.38$  cm). Similarly a female gibbosa chamber had a length and width of 2.4 and 1.8 cm. The height of these egg chambers was about 0.6 cm. Recently (1982) observed similar egg chambers.

After assaying the number of eggs in the laboratory, I placed them in an artificial egg cell. Two of the batches of eggs that were so treated were attacked by fungus. Both crickets may have some mechanism that prevents fungus from destroying the eggs, since I found no rotting eggs in chambers colonized by captive male crickets.

In more than 15 occasions, I have examined the living burrows of gigantes and viridulus both in the laboratory and in the field. The two species have similar sleeping burrows. Each burrow has a 3-5 cm sleeping chamber (width) 3-4 cm below the soil. This chamber has 2 openings, a narrow passage that opens at the ground surface and two side tunnels that are connected in other burrows. The narrow passage (3 cm diameter) that leads to the surface coming from the hole was 1-2 cm long and had an angle of 30-45° to the ground level. Bennett-Clark (1950) found special chambers for sleeping in G. pygmaea and G. pinnata. These chambers differ from those of gigantes and viridulus by having two surface entrances.

Many investigators have been concerned for male crickets during the last 2 decades, but it is very difficult to evaluate the efficacy of an insecticide for soil arthropods. One of the methods used in the past was to count the number of dead (or moribund) insects on the surface after the application of baits or dusts. In the case of male crickets, Schmidt and Salinger (1950) have taken into consideration the burrowing activities of adults, in addition to the above counting methods.

The results of experiments (Table 3-1) show no significant differences among the 3 treatments. Furthermore, there were live male crickets found under the soil surface. In the past experiments I found dead nymphs, not only on the surface ( $n = 3$ ), but also underground ( $n = 4$ ). There was no

activity in the control plot

It is clear that mortality occurred not only on the surface, but also under the soil. Therefore, counting the dead mole crickets on the surface does not represent the true efficiency of a bait or chemical. Sampling of burrows for mole crickets in the field should be done with caution. Removing the live mole crickets after the experiment, measuring the surface burrows, counting the dead mole crickets on the surface (and if possible digging the ground plots for dead ones on the soil) are some methods that could be used for evaluating the value of a chemical for mole cricket control.



## CHAPTER 4 OPTICS

In Gainesville, Florida, the biology of wolf spiders, Lycarctops  
gibbosus and L. villosus, was studied during 1973 and 1974. While I was  
studying their ecological behavior, I found the females feeding near the  
calling males and entering traps their larvae (Fig. 4.1). When calling  
males of gibbosus and villosus were introduced through window traps indoors  
(Fig. 4.2), large numbers of these two species flew to their respective  
calling males (Fig. 4.3). Photographs of orthopods was demonstrated in  
flight for the first time. Females attraction of large numbers of  
male spiders may be used as a control, either as a means of destroying  
crickets or as a means of curing the control procedures. The male  
spiders as attracted would not only include females, but also males  
(Fig. 5.1).

There are several problems in using sound as a control. I will  
analyze these each problem briefly. First, the sound trap—the speaker  
used to attract male spiders (Fig. 4.3)—is not effective on the  
calling adults and nymphs, and even those adults that do fly, do so  
only at a seasonal season. Adults of gibbosus and villosus only fly during  
spring and early summer, and fall (Fig. 5.1). Furthermore, the adults  
fly only in favorable weather conditions during the flight season (e.g.,  
days in which soil and air temperatures  $\geq 20^{\circ}\text{C}$ , flights do not occur).  
Therefore, sound traps can be used only on those days when gibbosus and  
villosus fly.

The second problem using sound as a control was the efficiency of the present sound trap. I was able to trap 28-33% of the "attracted" male crickets into the funnel, while the majority slipped the funnel and jumped into the trapping area. To increase the efficiency of the sound trap, the diameter of the capturing area should be increased. Alternatively, the feeding adults could be concentrated around the trapping area causing surface damage.

The third problem with using sound as a control was the effective range of sound trap. The diameter within which the male crickets can be influenced by sound factors, only some of which have been carefully studied. For instance, an intensity of 112 dB stimulated the maximum number of adults (Fig. 4.8), but it was not known from what distance they flew.

A part of my research dealt with methods to increase the number of attracted male crickets to the sound trap. I conducted a series of experiments systematically varying different parameters of calling songs on the response of flying gryllids. The number of male crickets trapped was found to be a function of carrier frequency and pulse rate (Fig. 4.10). These results proved that the catch of male crickets could be maximized by using appropriate parameters of calling songs. In gryllids, the maximum numbers were trapped with a sound of 2.7 kHz, 20 pulses per second, and 112 dB.

I also studied the appropriate time for broadcasting. Since gryllids and chironomus sang and flew after sunset (Fig. 5.2, Table 1.1), broadcasting should be started no later than 15-30 minutes after sunset and could be ended 30-45 minutes later.

I effectively put the sound trap to use in studying the other aspects

of male cricket biology. For instance, the dispersal of male crickets was studied with marking, release-recapture, and recapturing methods (Fig. 5.8). However, the recapturing efficiency was only 28 and this proved that at least 28 of the recaptured flies were also not caught. It seems that a considerable number may be flying more than once. Some individuals flew up to 8 weeks for the second time. It is probable that some females could lay their eggs and start flying again. Some individuals flew more than 5.2 km. It appears that the flight range of male crickets in Pennsylvania weather and wind may exceed a distance of 5 km. These results suggest that recolonization of a trapped pasture by flying adults could occur. Furthermore, the same pasture could be recolonized several times during the flight season.

While examining the crop contents of male crickets, I found 50% of the flying adults had an empty crop (Table 8.1). These results suggest that upon arriving in a new habitat, the "hatched" adults would cause severe injury to feeding on the plants.

Finally, studies on the effectiveness of the chemical baits on male crickets showed that some male crickets die not only on the surface, but also inside their burrows (Table 9.12). These results would indicate that crawling dead or moribund male crickets on the surface alone would not measure the effectiveness of a chemical.

Table 3.1. Starting time of sleeping and flight in *glingay* and *chlong*.

Species	Sleeping starting time			Flight starting time				
	Days observed	Minutes after sunset			Days observed	Minutes after sunset		
		$\bar{x}$	SD	Range		$\bar{x}$	SD	Range
<i>glingay</i>	17	27 <sup>ab</sup>	8	15 to 45	21	25 <sup>ab</sup>	5	20 to 44
<i>chlong</i>	25	12 <sup>ab</sup>	7	0 to 21 <sup>ab</sup>	28	12 <sup>ab</sup>	7	10 to 31

<sup>ab</sup> On 30 March and 6 June 1975, *glingay* were 17 and 8 minutes before sunset.

<sup>ab</sup> Means are significantly different ( $p < 0.05$ ).

Table 3.2: Descriptors of wild-calling songs in *Agropyron repens*. 10-10% (n = total number of calling songs analyzed for the parameter)

Parameter of calling songs	<i>Agropyron</i>	<i>Alouatta</i>
<u>Frequency (Hz, 10-10,000)</u>		
n	30	60
$\bar{X}$	68.9	65.4
SD	12.8	8.8
Range	42-104	53-94
<u>Carrier Frequency (Hz)</u>		
n	30	60
$\bar{X}$	4.40	3.28
SD	0.14	0.28
Range	2.4-5.0	1.8-3.4
<u>Ratio (Hz, 1/1000/10000)</u>		
n	30	60
$\bar{X}$	54.3	126.3
SD	4.4	23.3
Range	40-68	100-160

Table 4.1. Attraction of urban flying insects to broadcast songs of male 640 or 32 pulses per second, 1.7 kHz

Subfamilies and species	Number attracted			Baiting songs of attracted species (DFT)		Source of <u>collected</u> song
	♂	♀	Total	p/s	kHz	
<b>Ceryllinae</b>						
<u>Ceryllus rubens</u>	10	16	26	55	1.8	Natural and Synthetic
<b>Securithinae</b>						
<u>Securithus ruber</u> <u>Securithus</u>	6	11	17	60	2.8	Synthetic
<b>Neurothinae</b>						
<u>Neurothina</u> <u>Neurothina</u>	8	0	8	50	2.3	Synthetic

Table 5.3. Species specificity of note setting songs in *Eryllus cyathus*.  
(total of 3 trials) (n/s = notes per second)

Species and note frequency	Notes/second	
	<u><i>E. cyathus</i> song</u> (4.1/sec, 50 n/s)	<u><i>g. luteus</i> song</u> (2.7/sec, 33 n/s)
<u><i>E. cyathus</i></u>		
<i>E</i>	3	0
<i>T</i>	1	0
Total	5	0
<u><i>g. luteus</i></u>		
<i>E</i>	0	0
<i>T</i>	0	60
Total	0	60

Table 3.1: Wingbeat frequency of female *A. nigroparvum* ( $n = 20$ ) at 20 °C at air temperatures and 10% relative humidity.

Statistic	Duration of flight (seconds)	Wingbeat <sup>a</sup> Frequency	Thermal temperature after flight (°C)
Mean	17	100	20
SD	14	40	3
Range	2-43	60-140	17-23

<sup>a</sup>Hz per minute



Table 6.1. Root-to-stem temperature of *Pinus sylvestris* recorded simultaneously with the sap flow signal at the Ball-Court.

Date of observation (2007)	n	Relative humidity (%)	Temperature (°C)		Stem-to-stem temperature (°C)		
			Air	Soil	T	SC	Range
21 May	5	85	24.8	15	15.1	0-27	10.0-15.5
4 June	2	88	25.8	15	18.8	1-38	17.0-19.8
4 June	2	66	24.5	15	18.5	0-18	17.0-19.8
24 June	4	78	24.0	—	17.5	0-38	15.0-19.8
1 July	2	85	28.8	17	18.8	—	—

Table 6-1. Status of crop in flying and weeding practices and risks.

	Number of subplots examined	Percentages in the total examined	
		crop empty	crop established (and
<u>Flying subplots</u>			
<u>practices</u>	48	34	34
<u>risks</u>	64	42	11
<u>Weeding subplots</u>			
<u>practices</u>	18	33	28
<u>risks</u>	18	28	28

Table 2.1: The effect of insecticide baits on wireworms

	Insecticide (20 mg/20-1 T kg A. (baits)) <sup>a</sup>			
	Baited	lytic	flattened	Control
Replication		Number dead on the surface <sup>b</sup>		
1	2	2	3	0
2	0	0	1	0
3	0	0	0	0
Total	2	2	3	0
Replication		Number alive after 4 days <sup>c</sup>		
1	2	0	2	2
2	0	0	0	0
3	0	0	1	2
Total	2	0	3	4

<sup>a</sup> active ingredients

<sup>b</sup> surface area of each plot was  $2 \text{ m} \times 2 \text{ m}$

<sup>c</sup> an area of  $1 \text{ m}^2$  was sampled in each plot at random. To calculate the number of alive wireworms in each plot, multiply each number by 2.





Figure 1 1 The air sampling setup of aerosol and physics was mounted in the field with a portable light recorder (C) and a microphone (B) mounted on a camera tripod (B). The burner (A) of sampling tube is directly below the microphone.



Figure 1-2. (a) The variation of pulse rate vs carrier frequency for *agelaius* and *glaucus* in calling songs (400 = pulses per second). The vertical line indicates the total variation of a given pulse rate, the broad portion of the line is 2 Hz on each side of the mean. (b) The carrier frequency of *agelaius* and *glaucus* songs. The numbers above the bars indicate the actual number of calling songs having that particular frequency. The height is the number of songs expressed as a percent of the total songs of that species analyzed for carrier frequency.

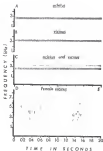


Figure 3.4. Spectrograms of male and female songs of male arribas.

(A) Calling song of *arriba* at 15°C (air temperature)

(B) Calling song of *arriba* at 15°C (air temperature)

(C) Calling songs of *arriba* and *arriba* at 15°C  
(air, A + B)

(D, E) Female songs of *arriba* at 15°C (air temperature)

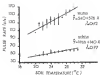


Figure 3-3. The effect of well interventions on the sulfate rate of solution.  $y = 3.6x - 52.8$  and  $R^2 = 0.97$  for black wells and  $y = 1.9x + 140.4$  and  $R^2 = 0.99$  for white wells. The regression lines are calculated on all individual values. The vertical lines show the range on each side of mean (g/d = grams per liter).



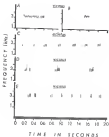


Figure 3-6. Spectrograms of aggressive and courtship songs of male crickets. The temperatures (bold and italics) are given for each song.

(A) Aggressive sounds of greeting in the presence of a male greeting at 18 and 18°C.

(B) Aggressive sounds of greeting in the presence of a male greeting at 18 and 18°C.

(C) Courtship sounds of male greeting at 18 and 18°C.

(D) Courtship sounds of male greeting at 18 and 18°C.

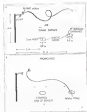


Figure 4.1: (A) Hole crickets could be seen flying near the light.  
 (B) Flying Roach wings landed near the entrance to the tunnel where hole crickets were sleeping.



- Figure 4-2 (A) Broadcasting electronics used in outdoor experiments. A pair of portable tape recorders (Dv) and a pair of portable amplifiers (Dd) were housed in a station wagon.
- (B) The funnel (Dn) along with a speaker and a jar (Dd) is referred to as a model trap.
- (C) The sound traps were placed 3-10 m apart and the control (Dd) trap had no speaker (Dd).
- (D) Attraction of flying into attract (Dn) to the broadcasting outdoor loudspeaker.
- (E) Tethered gliders flying to the laboratory.



Figure 4.3 Specificity of response of flying gnatcatchers and vireos to broadcast recordings of (a) natural and (b) synthetic drilling songs. Individuals natural to songs broadcasting conspecific songs are indicated by black bars. Others are indicated by open bars. Each bar shows the percentage of the total number of a sex and species that was captured by song during the trials with natural songs or during the trials with synthetic songs. The number of individuals is indicated above each bar (n/a = none per session).



Figure 4-4 The proportion of fascicles in galley and vanner that were raised at various times during the 1976 season. The numbers above the bars indicate the ratio of galley to total number of fascicles recorded for spurs in the spermophore on that date.

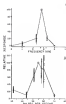


Figure 5-3. The response of flying crickets to synthetic sounds that were optimally suited to frequency (A) and to pulse rate (B). A standard sound-response curve with 2.2 kHz, 40 pulses per second (pps) for testing frequency, 2.2 kHz, 55 pps for testing pulse rates was taken as a reference sound. The number of crickets trapped to the standard sound (B) was taken as 1000 crickets. The relative response was calculated as a percentage of those trapped at the standard sound. Vertical bar is  $\pm 2$  SD at either side of the mean. A total of 415 male crickets was trapped in 15 frequency trials, and 845 male crickets in 15 pulse rate trials.



Figure 5.4. The response of flycatchers to various intensities. All trials used the same flycatcher intensity (2.7 kHz, 55 pulses per second) sound. The reference sound was 100 dB intensity and the number of male flycatchers trapped in the standard 100 intensity was taken as 100% response. Relative response is the number of male flycatchers trapped as a percentage of those captured at the standard intensity.  $\pm 1$  = result of a single trial with a different operator. The dotted line represents a doubling of the number of male flycatchers trapped for each 5 dB increase in intensity. Vertical bar is  $\pm 1$  standard error of mean.



Figure 2:—The flight collection of *aphids* and *flies* monitored by ultraviolet technique during 1971 (a), and 1972 (b). The relative capture in the number of *aphids* or *flies* captured on a particular date as a percent of the total captures of that species during the season. During 1972-1973 (c), a total of 199 adults was captured. The nights in which both *aphids* and *flies* flew are shown by crosses.





Figure 5-8. The ratio of numbers (84) and (19) collected using traps (1987) and (1) the broadcasting method (1988). The numbers above the bars are the actual numbers collected. The relative amount is the number captured of a particular one by a particular method during a year expressed as a percent of the total captures of that method and year.



Figure 5.3. Fluctuation in the population of flying gnats and midges during a night, determined by bioassaying techniques. The number trapped is the number of male trichets collected in the insect trap during a 5 minute period. Arrows show the sunset time. Vertical line is 3.00 on another side of moon diary. For gnats population was made during 4 days and diary of midges was made on 26 April 1974.

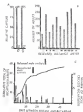


Figure 2. a) Mating, releasing, and recapturing of *galleriae* were carried out during May to July 1973. b) Total of 1000 female adults were released in the field (MC) and 10 of the adults were recaptured (MC). c) Some adults ( $n = 100$ ) flew more than one night and d) flew more than 2 nights (MC). The same day is the date of mating and releasing in the field. The number above the bar is the actual number of males and females used. Relative figures in the total number of these numbers of that was released. Significance ( $P < 0.05$ ) of the time type represented a single individual when was captured during

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#### EDUCATION, 1945-1950

R. M. Wagner (known as Raj) was born on 6 March 1934 at Kalyanpur, (Tant) Kala Hathi, India. Raj completed his high school education in 1950 at the end of eleven years of schooling. In May 1954, he graduated from the College of Agriculture, University of Madras. He served in the Department of Agriculture, Government of Madras, as Research Assistant for four years. He was awarded the Government of Madras Scholarship during 1954-58 to pursue his graduate studies. In August 1955, he received his Master's degree in Entomology at the Indian Agricultural Research Institute, New Delhi 110012. Raj has worked toward the Doctor of Philosophy degree in the Department of Entomology and Zoology from September 1955 and has been employed as a graduate teaching and research assistant during his graduate training. He is a member of several scientific societies. Raj was two months at the Florida Entomological Society annual meetings for his research paper on ticks or ticks.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

  
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